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RF Attenuation in Pressure Compensating Dielectric Fluid

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ABSTRACT Non-compressible dielectric fluids have been used as Pressure Compensation Fluids in a variety of high voltage equipment in submarine applications. This type of electrically-insulating heat transfer fluid is used for immersion-cooled thermal management of electrical devices as well as to equalize external hydrostatic pressure at ocean depths. An investigation has been conducted to determine the attenuation characteristics of a single-phase dielectric heat transfer fluid to RF emissions in the frequency range of 500 kHz to 6 mHz. Results indicate that transmission losses were extremely low across this range; well within acceptable limits. Application of this knowledge can be used in immersion-cooled thermal management products involving RF propagation and as a Pressure-Compensation Fluid in antenna radomes.

INDEX TERMS immersion cooling, pressure compensation, radome, RF propagation

I. INTRODUCTION

RF Transmission systems, as other electronic components, have seen two major trends over time: packaging miniaturization and higher power capacities. Both trends have converged to make thermal management a limiting factor in the development of next-generation communications systems. [1,2]

Cooling performance with forced-air cooling is limited due to the low heat capacity of air. Tremendous volumes of air must be moved past hot components to compensate for this. In addition, airflow is restricted in closed environments, such as aerospace, military vehicles and enclosed radomes covering RF transmission antennas.

An alternative cooling technology, called Single-phase Liquid Immersion Cooling (SLIC) is becoming more popular as a leading Thermal Management Technology for electrical devices [3][4].

In addition to Thermal Management applications, many dielectric fluids are lighter than water, and have a low compressibility factor [high bulk modulus], making it possible to use them as a pressure compensation fluids for filling submarine antenna radomes.

II. IMMERSION COOLING

With higher power capacity and miniaturization of electronic and electrical devices, thermal management has become critically important in manufacturers' ability to develop next-generation equipment. So-called "free air" cooling has reached its limit to control temperatures in high powered RF amplifiers. Single-phase Liquid Immersion Cooling [SLIC] Technology has emerged as the leading enhance thermal management technique [5].

With SLIC Technology, a hot component or piece of hardware is immersed directly into a pool of a dielectric heat transfer fluid. The device can be electrically "live", and can be immersed directly into the dielectric fluid, without the need of a "cold plate" or other indirect cooling method. The fluid is usually contained within a loop consisting of a pump, a radiator and a chamber where the hot electrical device is located. The flowing liquid is warmed as it passes by the hot electrical component. The fluid is pumped through a heat exchanger [very often a radiator] where the heat is lost, then the fluid returns to the electrical component to pick up more heat.

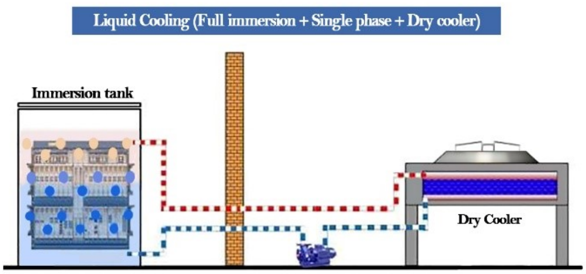


Figure 1: Single-phase Immersion Cooling Loop

Besides the ability to handle high heat flux inputs, SLIC technology has demonstrated the following advantages over forced air cooling [6]:

- Temperature Stability – Immersion in a single-phase liquid eliminates temperature variation or excursion. Operating temperatures are kept with a narrow band that's optimized for efficiency and equipment life.
- Protection from airborne dirt, dust, moisture, acids and other contaminants.
- Longer service life – SLIC Technology is proven to raise MTBF of electrical equipment.
- Lower cooling costs.

III. RADOME PRESSURE COMPENSATION

Radomes are rigid coverings used for external protection of radio antennas for ground, airborne and for submarine applications. For under water applications, Radomes must have high stiffness, and high strength to weight ratio to withstand water pressure at extreme depths. For example, at 490 meters depth, a submarine radome must be able to withstand 50 bars of pressure [7] The radome's impact on the electromagnetic transmission by the enclosed antenna must be minimized [7].

Figure 2: Antenna Radome

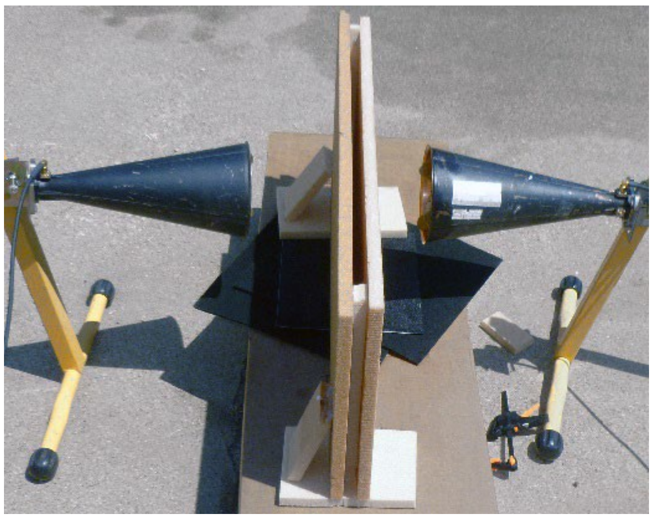
Flooding an undersea radome with a noncompressible Pressure Compensation Fluid equalizes the external pressure and eliminates the need to build these radome with heavy materials [8][9].

Beyond standard criteria for a suitable dielectric heat transfer fluid for cooling electronics, Radio Frequency transmission has some unique requirements, namely transparency to the entire spectrum of radio frequencies and a material dielectric constant [K] that doesn't vary across the frequency spectrum range of the applied voltage [10].

IV. RF TRANSMISSION TESTING

This investigation involved testing the dielectric heat transfer fluid for RF transparency. The insulating fluid tested was AmpCool® AC-110 Dielectric Coolant, manufactured by Engineered Fluids, Inc. A customized test fixture was constructed, using a material normally used to as a core material in aircraft radomes due to its RF transparency. Within the foam was a cavity of 0.5" or 1.0" inch that contained a thin plastic liquid test cell.

This test setup is common to a wide range of radome and RF materials testing. Antennas used were calibrated to match the frequencies being tested. Insertion loss was tested at 90° of



incidence at 500 MHz and over 1 ~ 6 GHz at two sample thicknesses with low, known losses.

Figure 3: RF Attenuation Test Cell

V. RF TESTING RESULTS

Table 2 shows the results of RF attenuation testing.

**RF SIGNAL ATTENUATION
AMPCOOL AC-110 DIELECTRIC COOLANT**

	FREQUENCY			
	500 MHz	1 GHz	3 GHz	6 GHz
AmpCool AC-110 12 mm Path	+0.15 dB*	-0.10 dB	-0.10 dB	-0.00 dB
AmpCool AC-110 24 mm Path	+0.20 dB*	-0.10 dB	-0.10 dB	-0.05 dB
Water [Control] 24 mm Path	-------	-8.00 dB	-18.00 dB	-42.00 dB

*Amplification of the test signal in these cases is an artifact of reflected waves within the test cell.

Figure 4: Signal Attenuation vs. Frequency: 12mm Path Engineered Fluid AmpCool AC-110 Dielectric 1 ~ 6 GHz @ 90

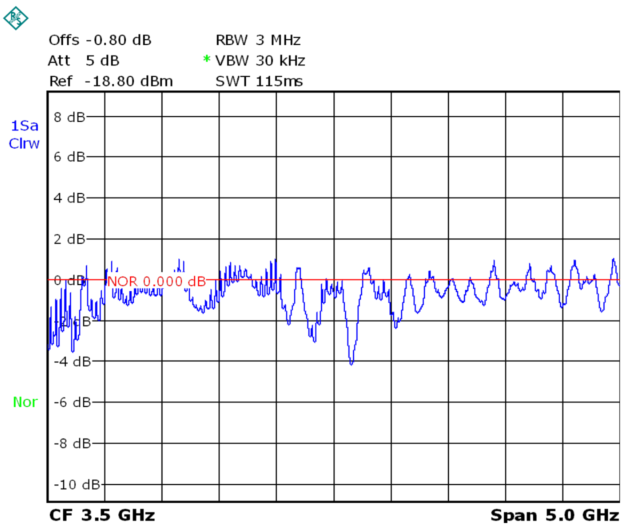
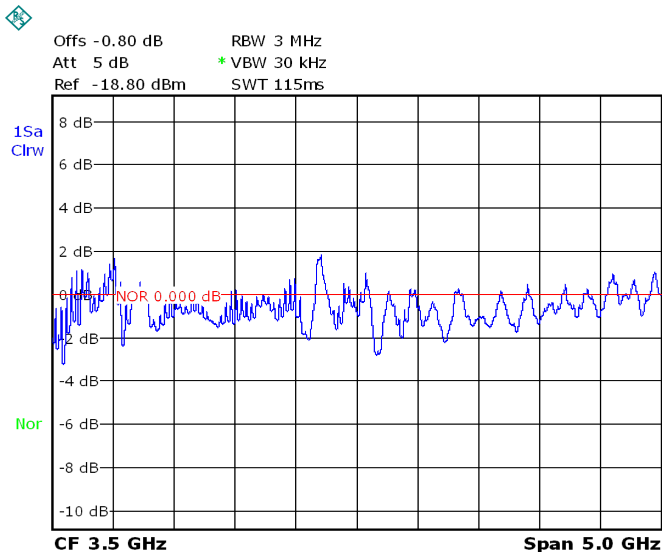


Figure 5: 25mm Path Engineered Fluid AmpCool AC-110 Dielectric 1 ~ 6 GHz @ 90



VI. DISCUSSION

At reference frequencies of 500 MHz, 1.0, 3.0 and 5.0 GHz, the RF loss was less than 0.1 dB. Absorption maxima were seen at 4.28 GHz.

Typically, RF absorption of commercially-available radar radomes through this frequency range is 0.3 – 1.0 dB [10]. This experiment demonstrates that RF transmission through the chosen single-phase dielectric coolant, AmpCool AC-110, is possible with low losses in the frequency range tested. Implications of this knowledge include development of fluid-filled pressure compensating radomes and the use of immersion cooling for thermal management of RF antenna.

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